Thermodynamics of Madden-Julian Oscillation in a Regional Model with Constrained Moistening

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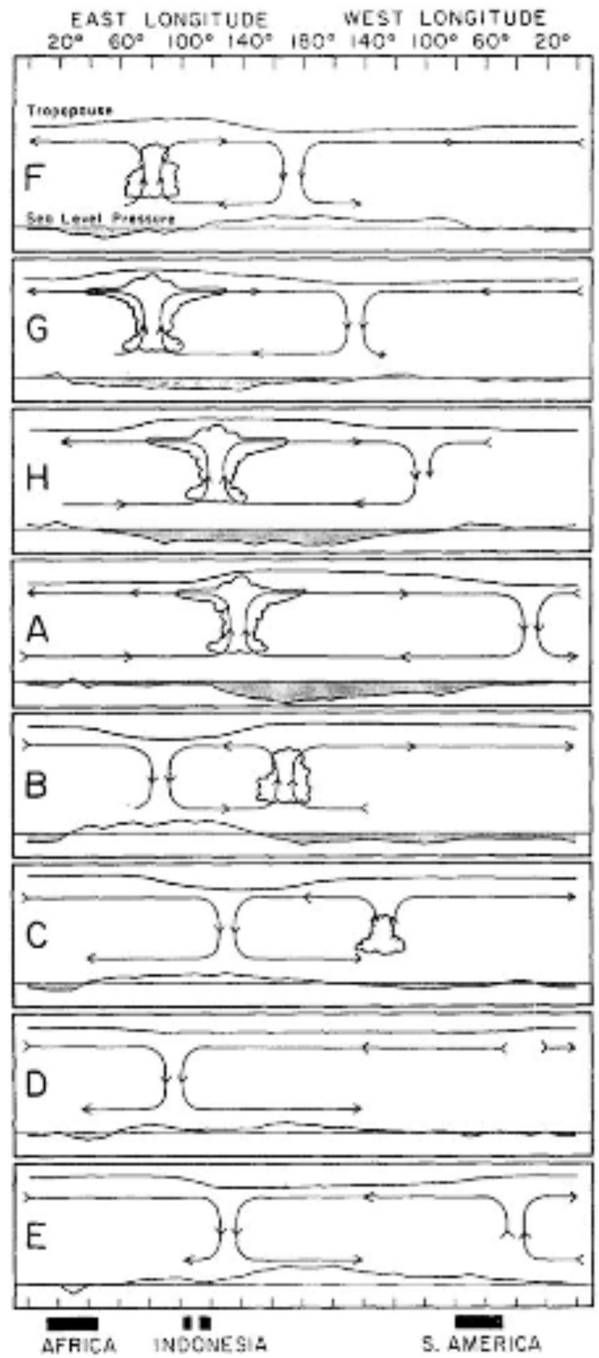
Background

- MJO refers to the planetary scale organization of atmospheric circulation and moist convection in the tropics that propagates eastward at an average speed of 5 m/s across the equatorial Indian and western/central Pacific oceans, with an intraseasonal period of 30 – 90 days
- The dynamics of MJO involves atmospheric planetary-scale circulation and its interaction with mesoscale convective activities
- MJO influences rainfall in the Pacific islands, Asian monsoon, west coast of North America, South America, Africa, and tropical cyclone activities
- A comprehensive understanding of MJO is lacking because models do not adequately represent moist convection and its interactions with the environment



Objectives

- To produce a realistic simulation of MJO through observational constraints

- Analyze the thermodynamic budget based on the simulation to identify the main sources and sinks of energy associated with MJO convective activity and the roles of various types of instabilities in the propagation and lifecycle of MJO

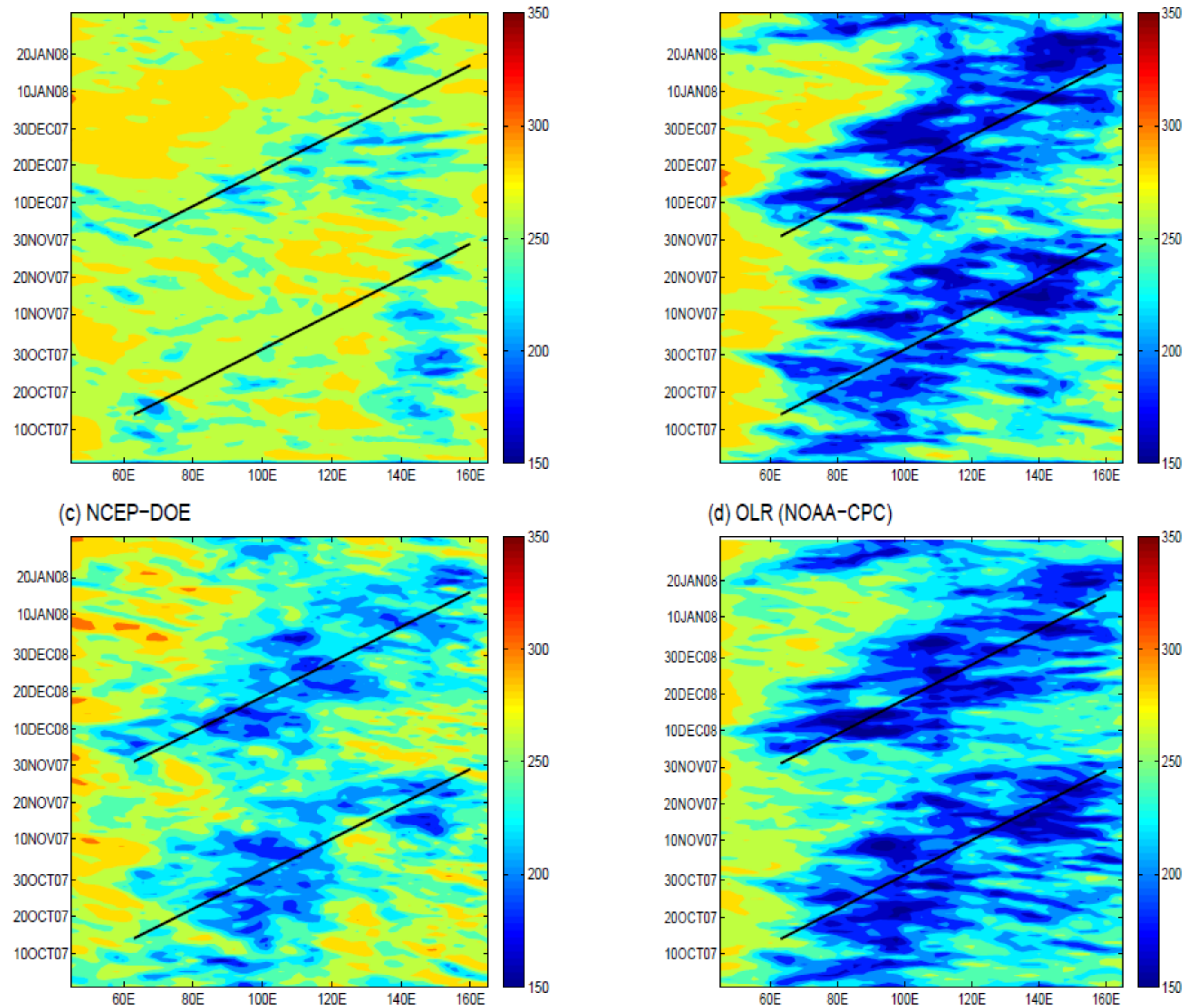
- Evaluate the effect of observational constraints to gain insights into physical processes that are critical for a robust, realistic simulation of MJO in models

Approach

- WRF is applied at 36km resolution over a domain that includes Indian Ocean and Western Pacific from 25S to 25N
- GFS forecast data are used to provide lateral, initial, and surface boundary conditions
- The Kain-Fritsch, RRTM/Dudhia, YSU and WSM-3 schemes are used to parameterize cumulus convection, radiation, PBL and microphysics respectively
- In the GFDDA experiment the simulated moisture for all grid points above the PBL is nudged toward the GFS analysis every six hours
- The NONUDGE experiment has no nudging in the interior of the domain
- Two MJO episodes observed between October 1, 2007 – January 31, 2008
- Although the moisture budget is not closed, the thermodynamic equation remains balanced for the given diabatic heating indirectly constrained by moistening

Comparison of simulated and observed OLR signals

Simulation w/o nudging | **Simulation with moisture nudging**



NCEP-DOE reanalysis | **NOAA-CPC observation**

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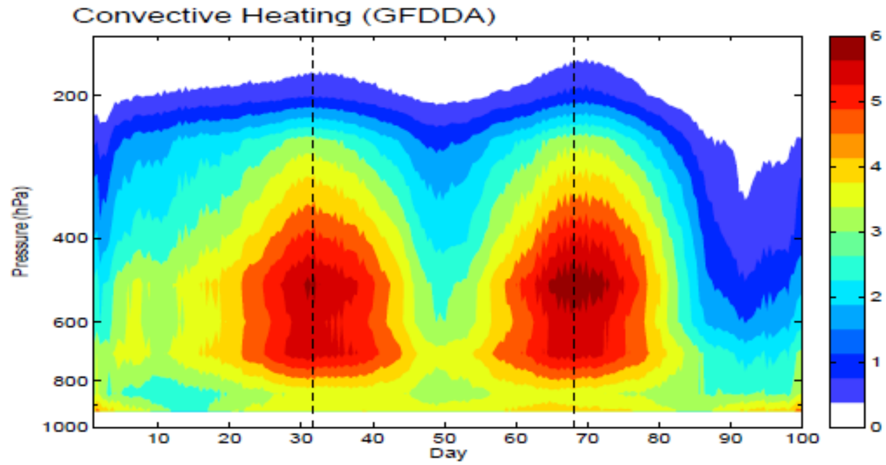
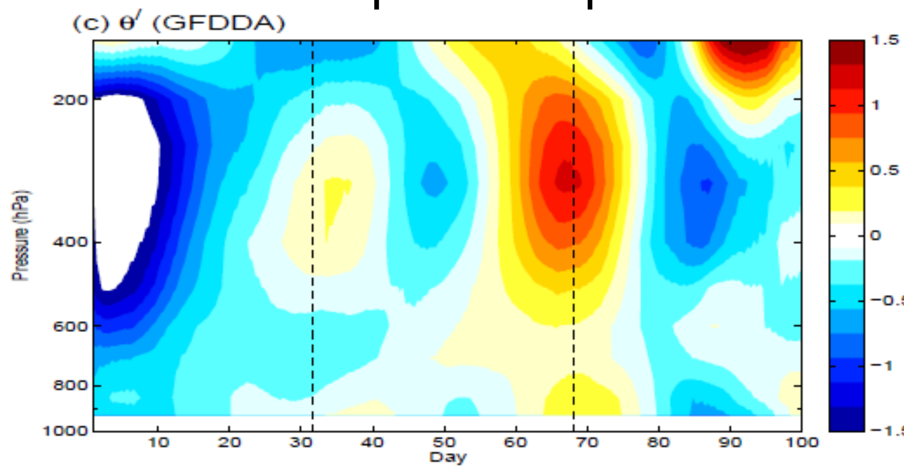
Composites from the GFDDA simulation

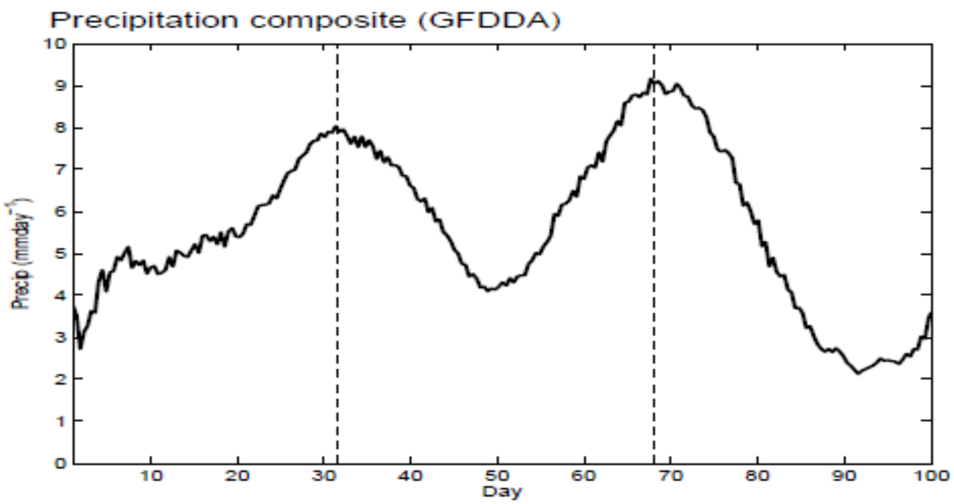
- Composites are developed using a frame of reference that follows the MJO that propagates at about 4 m/s
- Two MJO episodes are identified with peak precipitation at day 32 and 68 of the 120 day simulation

Convective latent heating



Potential temperature perturbations





Precipitation

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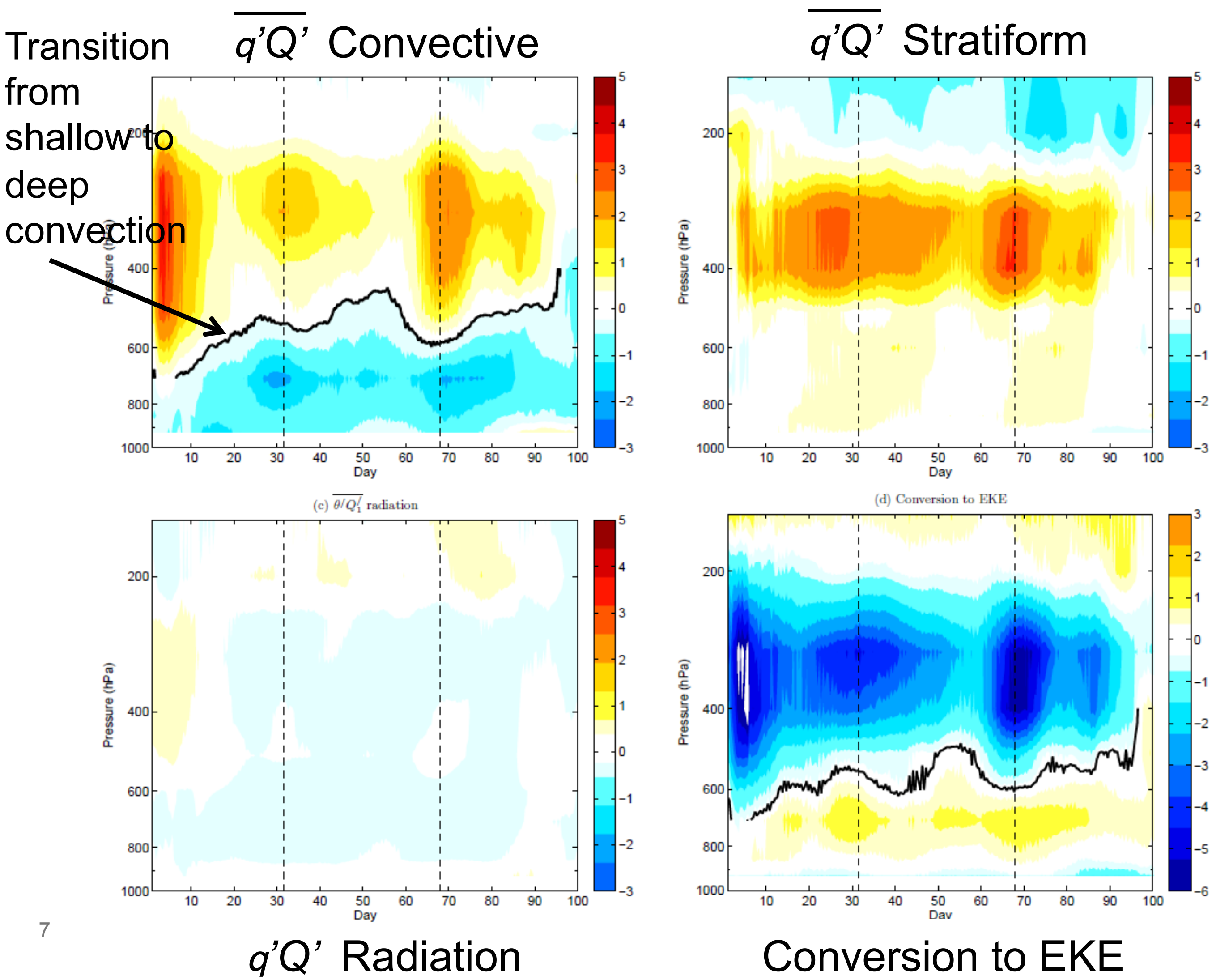
Sources and sinks of available eddy potential energy

$$\frac{\overline{\partial \theta'\theta'}}{2\partial t} = -\overline{\theta'(\nabla \bullet (v\theta))'} + \overline{\theta' Q'_{1(conv)}} + \overline{\theta' Q'_{1(stratiform)}} + \overline{\theta' Q'_{1(radiation)}} + \overline{\theta' Q'_{1(pbl)}}$$



- In the lower troposphere EKE conversion and stratiform instability are sources of EAPE and shallow convective heating is a sink (convective damping layer)
- In the upper troposphere stratiform instability and convective heating (wave-CISK) are the main sources of EAPE and conversion to EKE is the sink

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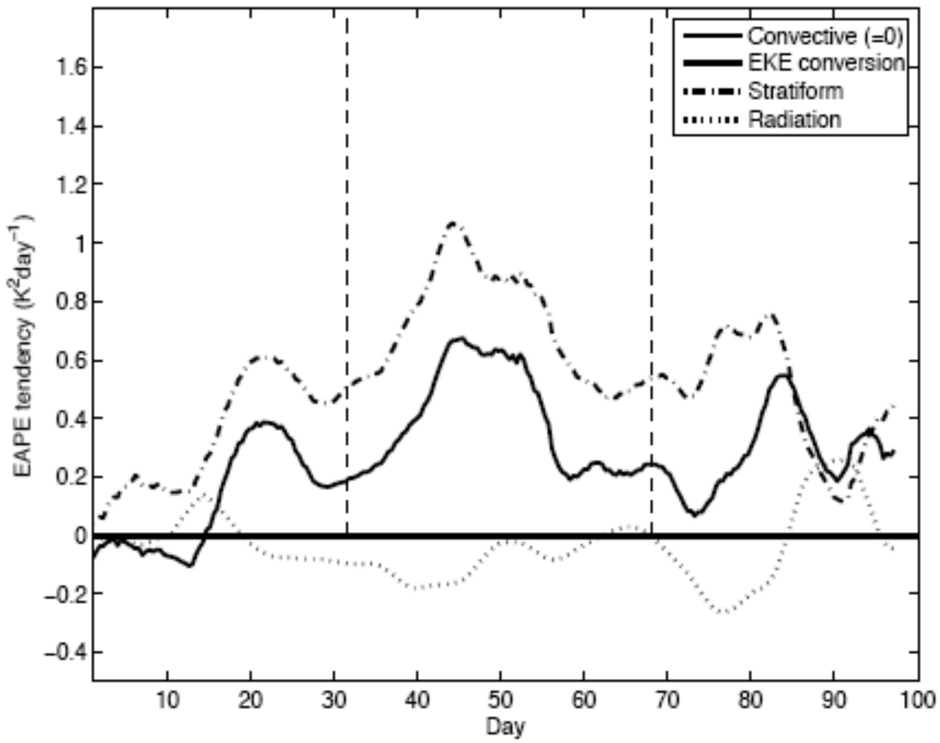
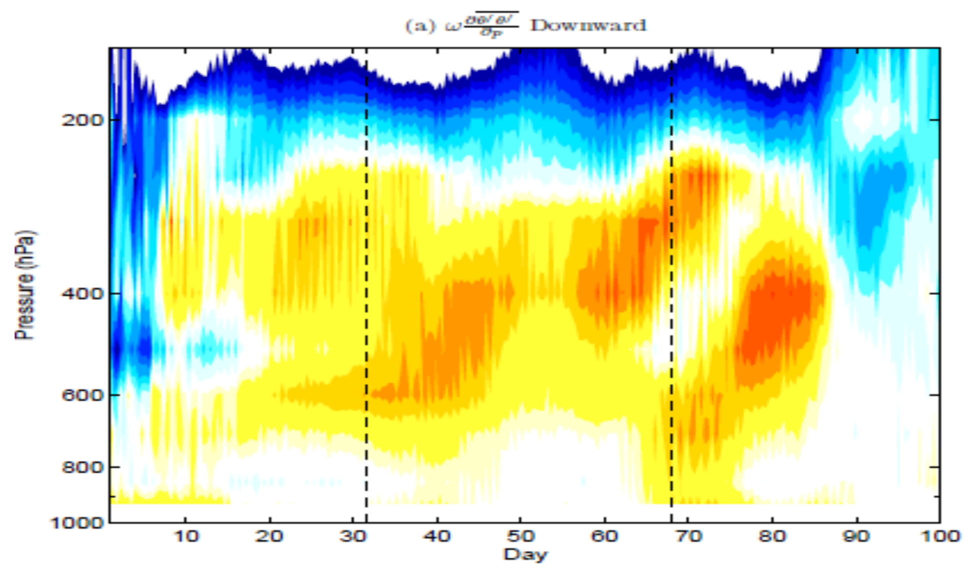
What triggers the transition from shallow to deep convection

- EKE is mainly provided by stratiform heating as the transition level progresses up and taps the energy from stratiform instability
- The subsidence of cold air provides the EAPE for gradual deepening of the convective damping layer toward the layer of stratiform instability upon which deep convection is triggered



EAPE budgets at the transition level



Downward transport of EAPE

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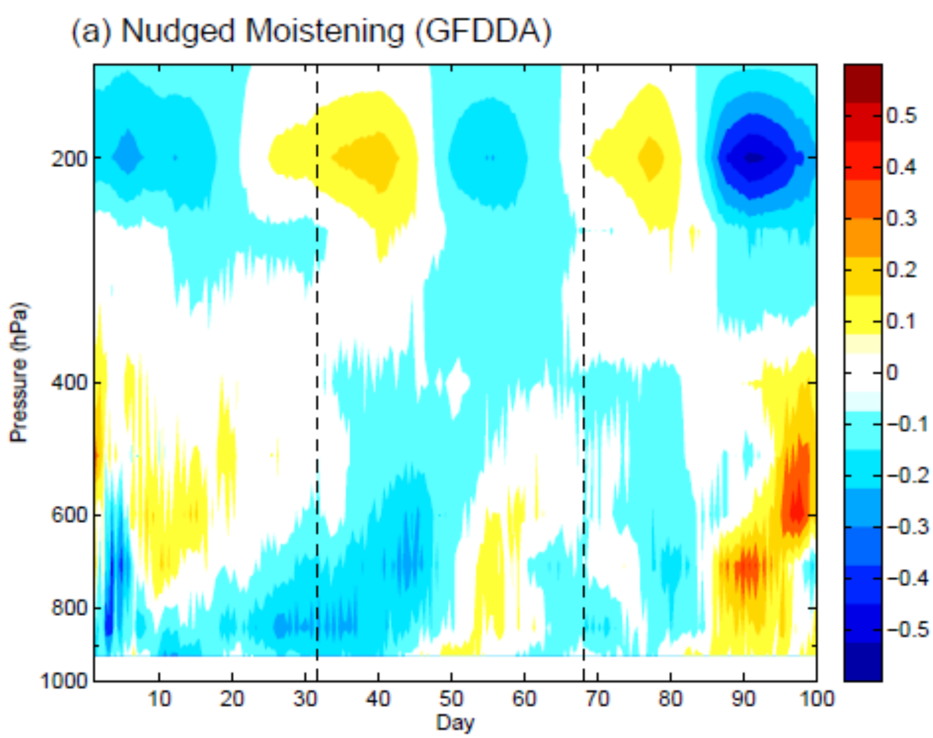
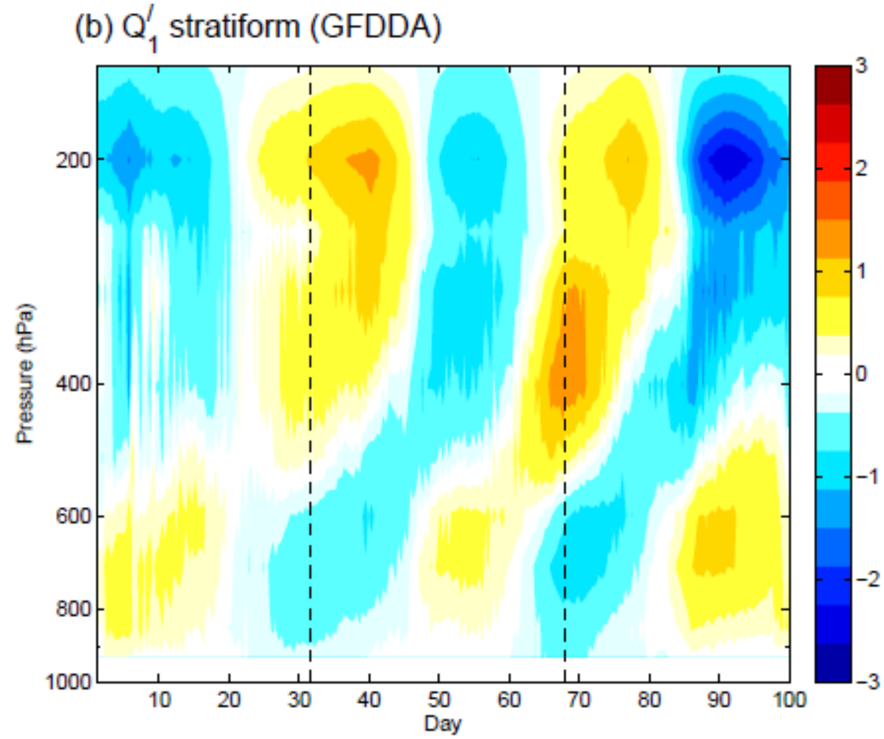
Perturbations by observational nudging

- Nudging moistens the lower troposphere about 15 days before the MJO peak precipitation and it moistens the upper troposphere for up to 15 days after the precipitation maxima
- The stratiform heating associated with low-level (and upper level) moistening during early (and late) stages of the MJO active phase results in EAPE generation throughout the troposphere
- The tilt in stratiform heating variability is needed for positive co-variability with potential temperature perturbation to generate constant stratiform instability

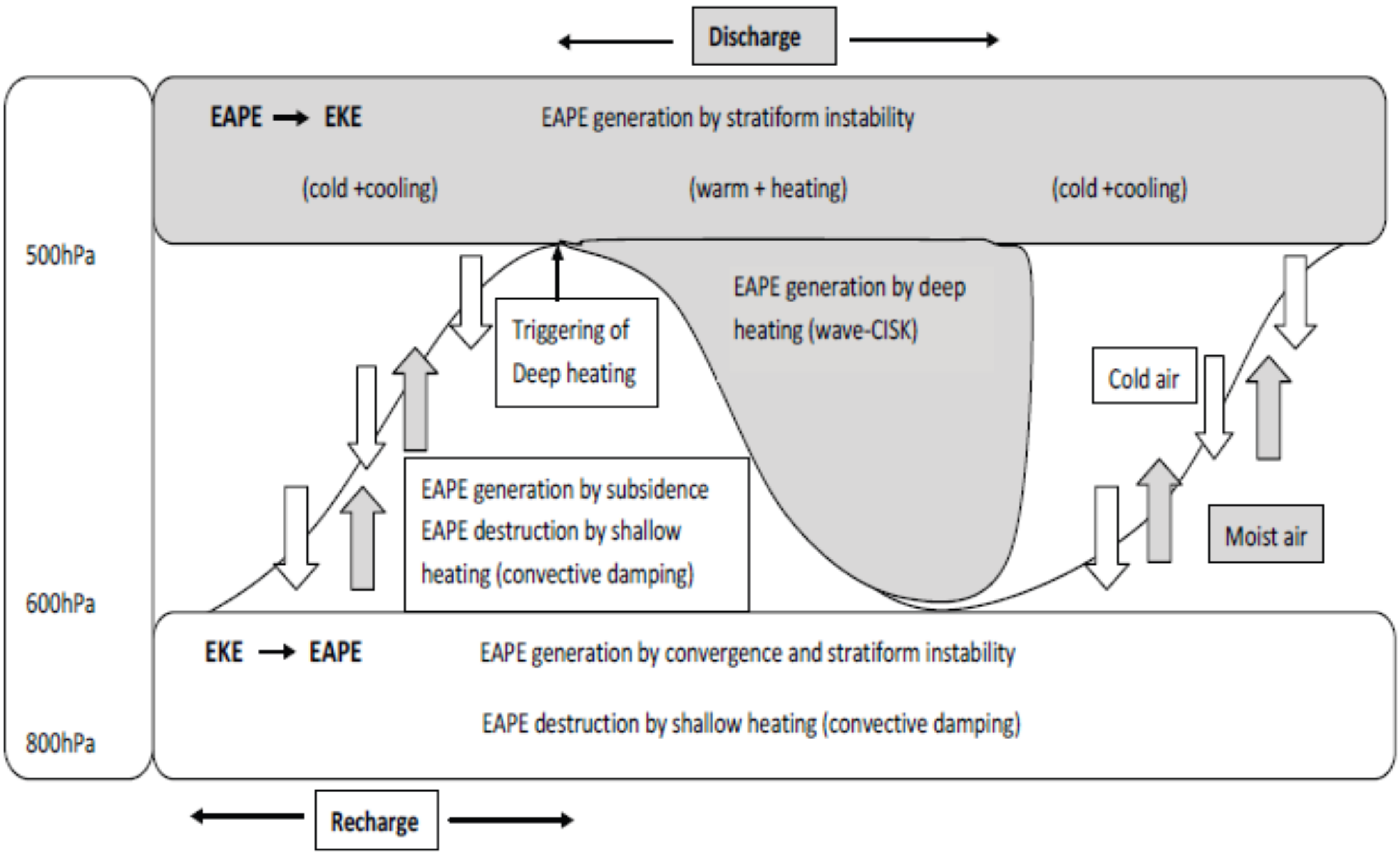


Perturbation of moistening



Perturbation stratiform heating

A simplified paradigm of MJO thermodynamics

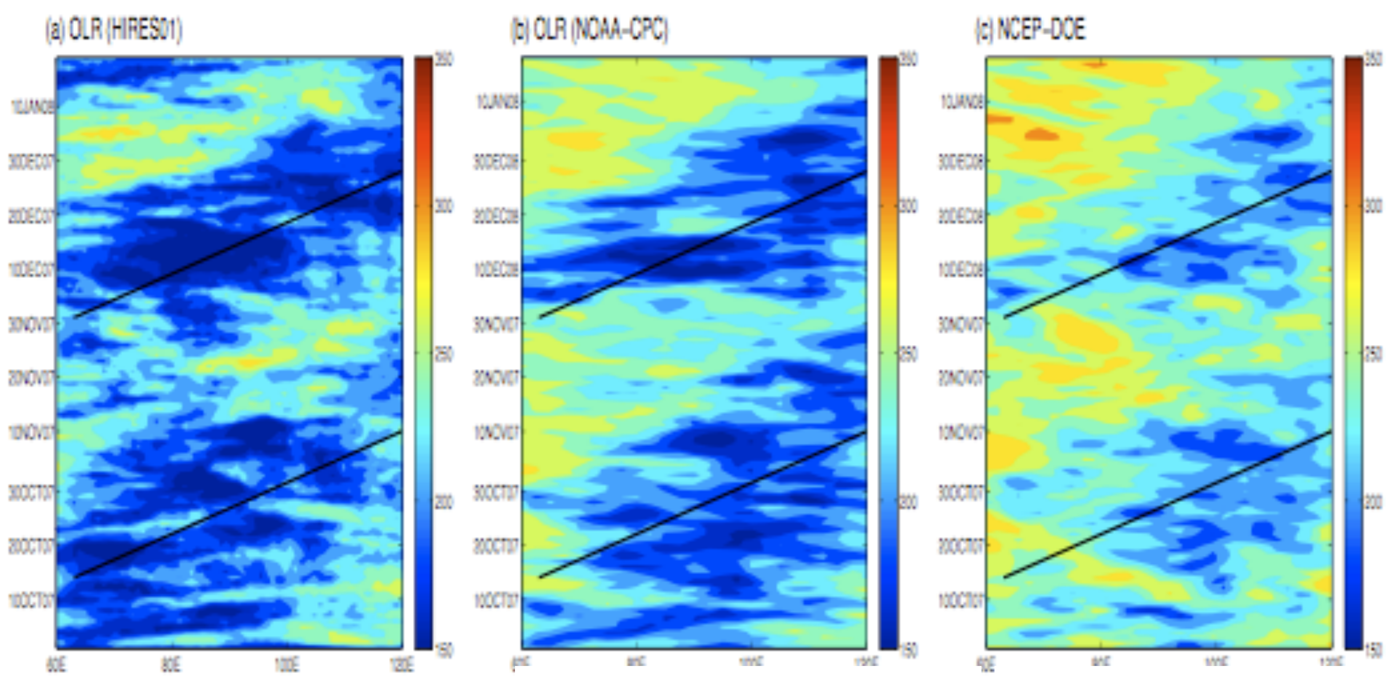


Summary

- The thermodynamics of MJO has been studied using regional simulations with constrained moistening
- Lower (upper) level moistening at the early (late) stages of the MJO active phase is found to be crucial for the life cycle of the MJO - it introduces the tilt in stratiform heating variability that interacts with potential temperature perturbations and provide an important source of EAPE
- Without moisture nudging, the regional simulation was not able to produce the necessary tilt in stratiform heating
- More sensitivity experiments using different combinations of deep and shallow convective parameterizations show some successes in simulating features of MJO, although the propagating signals for precipitation are still weak
- Cloud resolving simulations will be performed to further provide insights on both the thermodynamic and moisture budgets of MJO to guide parameterization development

Summary

- Regional models are useful for MJO study:
  - Different types of numerical experiments can be readily performed with grid or spectral nudging to produce realistic simulations for budget analysis
  - By imposing lateral boundary conditions, extratropical influence can be evaluated
  - It is feasible to perform cloud resolving simulations with the regional model dynamical core to explicitly resolve deep convection for a full energy and moisture budget analysis



WRF simulation at 4 km resolution **NOAA-CPC observation** **NCEP-DOE reanalysis**